STUDY AND APPLY THE PASQUILL-GIFFORD PUFF MODEL TO CALCULATE THE DISPERSION OF THE HAZARD SUBSTANCE IN THE AIR FOR ASSESSING THE ENVIRONMENTAL RISK CAUSED BY THE RECEIVER OF THE LIQUID PETROLEUM GAS (LPG)

Ly Ngoc Minh [(1)], Nguyen Van Quan [(2)], Dinh Xuan Thang [(3)]
[(1)] *Trường đại học Công nghiệp Tp. Hồ Chí Minh*
[(2)] *Phân viện nghiên cứu KHKT bảo hộ lao động tại Tp. Hồ Chí Minh*
[(3)] *Viện môi trường và tài nguyên - ĐHQG Tp. Hồ Chí Minh*

ABSTRACT

Our study introduces the method to calculate the dispersion of the hazard gas in the air for assessing the environmental risk caused by the receiver by using two mathematical models - the continuous model (plume model) and the instantaneous source model (puff model) - and ability to apply them in order to calculate the dispersion of the hazard gas in the air to predict the impact of the environmental risk in using the LPG in Vietnam.

Result of our study can use for assessing the environmental risk or predicting the consequence of the environmental risk in using LPG or the refrigerant or another hazardous chemicals.

I.   INTRODUCTION

Using LPG or the refrigerant or another hazardous chemicals can caused some environmental risks, such as: leaked from the tanks, rupture the tanks ... So we have to calculate the dispersion of the hazard gas in the air for assessing those environmental risk. One of the way is using the mathematical models to do this work. There are two mathematical models - the continuous model (plume model) and the instantaneous source model (puff model) as the show below.

II.   BASIC THEORY

There are two mathematical models - the continuous model (plume model) and the instantaneous source model (puff model) as below:

2.1.   Plume model:

The commonly used plume model was developed by Pasquill and Giford. The theoretical bases and derivations are described in a lot of books on environment. This plume model is a steady state model in Eq. 1.1:

$$C(x,y,z) = \frac{Q_m}{2 p s_y s_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{s_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H_r}{s_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H_r}{s_z}\right)^2\right]\right\} \quad \text{(Eq. 1.1)}$$

Where:
- C(x,y,z) is the concentration of the gas as a function of x,y,z (mass/length^3),
- x,y,z are distances from the source (length) (see Fig. 2.1)
- Q_m is the source (mass/time) ,
- s_y and s_z are dispersion coefficients (length),
- u is the wind velocity (length/ time), and
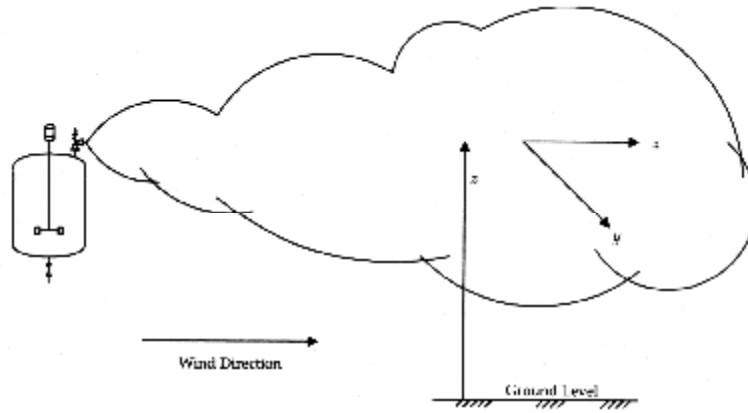- H_r is the height of the release (length).

Figure 1.1: Continuous source: plume model

When the source has a higher temperature than the local environment, and is projected in a vertical direction (e.g., from a vent stack), the release height is corrective for buoyancy and momentum:

$$\Delta H_r = \frac{\overline{u_s}\, d}{\overline{u}}\left[1.5 + 2.68x10^{-3}\, Pd\left(\frac{T_s - T_a}{T_s}\right)\right] \quad \text{(Eq. 1.2)}$$

Where
- ΔH_r is the correction to the release height (m),
- $\overline{u}_s$ is the stack gas exit velocity (m/sec),
- d is the inside stack diameter (m),
- $\overline{u}$ is the wind speed (m/sec),
- P is the atmospheric pressure (mbar),
- T_s is the stack gas temperature (K), and
- T_a is the air temperature (K).

The dispersion coefficients are function of the atmospheric stability classes and the downwind distance from the source. These stability classes are shown in Table 1.1 and the coefficients are given in Fig. 1.1 and Fig. 1.2. As indicated:

$$s_x = s_y \qquad \text{(Eq. 1.3)}$$

This plume model is also used to estimate the downwind ground level concentrations a ground – level source by setting $z = H_r = 0$

$$C(x, y, 0) = \frac{Q_m}{ps_y s_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{s_y}\right)^2\right] \qquad \text{(1.4)}$$

These equations can be manipulated algebraically to solve for the position of the lines equal concentrations (isopleths):

$$y = s_y \sqrt{2\ln\left(\frac{C(x,0,0)}{C(x, y,0)}\right)} \qquad \text{(1.5)}$$

2

Equation 1.3 is used to define areas with concentrations over a specific toxicity level or flammability level. These areas are subsequently used for evaluating consequence.

The ground – level concentration for above ground sources are determined with Eq. 1.1 while setting z = 0:

$$C(x, y, 0) = \frac{Q_m}{2ps_y s_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{s_y}\right)^2 - \frac{1}{2}\left(\frac{H_r}{s_z}\right)^2 \right] \quad (1.6)$$

A centerline concentration for this above – ground source is found by setting y = 0 in Eq. 1.4:

$$C(x, y, 0) = \frac{Q_m}{2ps_y s_z u} \exp\left[-\frac{1}{2}\left(\frac{H_r}{s_z}\right)^2 \right] \quad (\text{Eq. 1.7})$$

The maximum centerline ground – level concentration for a source above ground level is found using Eqs. 1.8 and 1.9:

$$C(x, 0, 0)_{max} = \frac{2Q_m}{epuH_r^2}\left(\frac{s_z}{s_y}\right) \quad (\text{Eq. 1.8})$$

$$s_z = \frac{H_r}{\sqrt{2}} \quad (\text{Eq. 1.9})$$

This maximum concentration is determined (a) by computing s_z with the Eq. 1.9; (b) looking up x in Fig. 1.2, which corresponds to this s_z; (c) looking up the s_y for the given x position; and then computing their maximum concentration with Eq. 1.8. Equation 1.5 can be used to determine the lines of constant concentration around this maximum value. This type of analyst is necessary step in evaluating alternative consequences.

The centerline concentrations for ground – level source are found using Eq. 1.1 and setting z=y=H_r = 0:

$$C(x, 0, 0) = \frac{Q_m}{ps_y s_z u} \quad (\text{Eq. 1.10})$$

As shown, this centerline concentration appears to be independent of x. The effect of x , however, is accounted for by the larger dispersion coefficients as x increases.

Table 1.1: Atmospheric stability classes for the Pasquill-Gifford dispersion model

Wind speed (m/s)	Day radiation intensity			Night cloud cover	
	Strong	Medium	Slight	Cloudy	Calm and clear
<2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

Note: Stability classes for plume model (A, B, C, D, E, F …) compared to stability for puff model (unstable, neutral, and stable): A, B (unstable), C, D (neutral), E, F (stable).
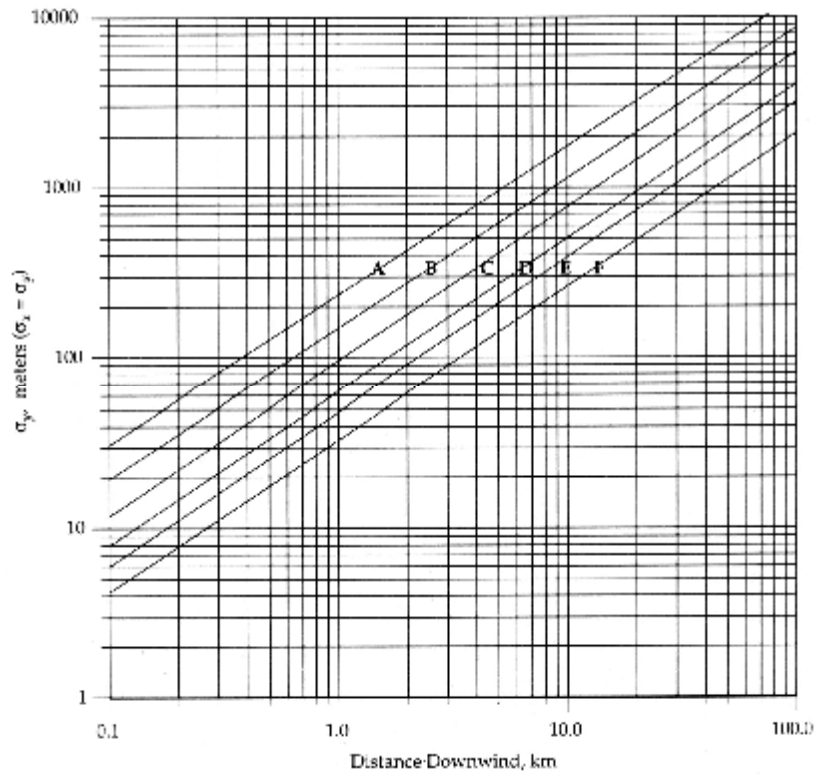
Figure 1.1: Horizontal dispersion coefficients for Pasquill-Gifford plume model
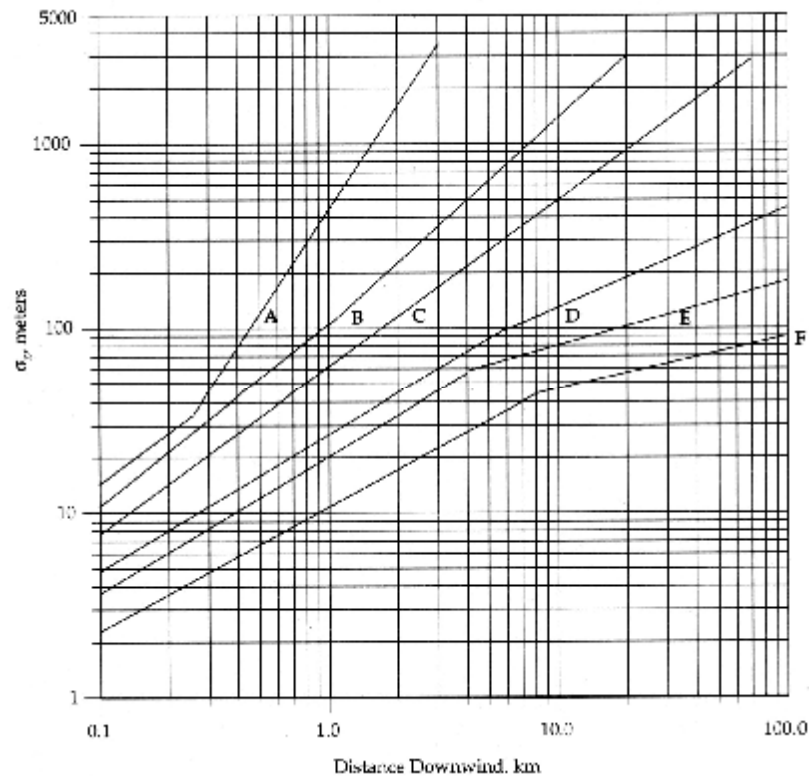

Figure 1.2: Vertical dispersion coefficients for Pasquill- Gifford plume model

2.2. Puff model

A puff is formed as a result of an instantaneous spill (see Fig. 2.1). Puff scenarios include catastrophic of bottles, drums, or vessels containing liquids above their normal boiling

4

points. Upon rupture, a fraction of the liquids vaporizes. The flashing vapor is a result of the excess sensible heat vaporizing a fraction of the liquid. This flashing vapor may also entrain some of the remaining liquid.
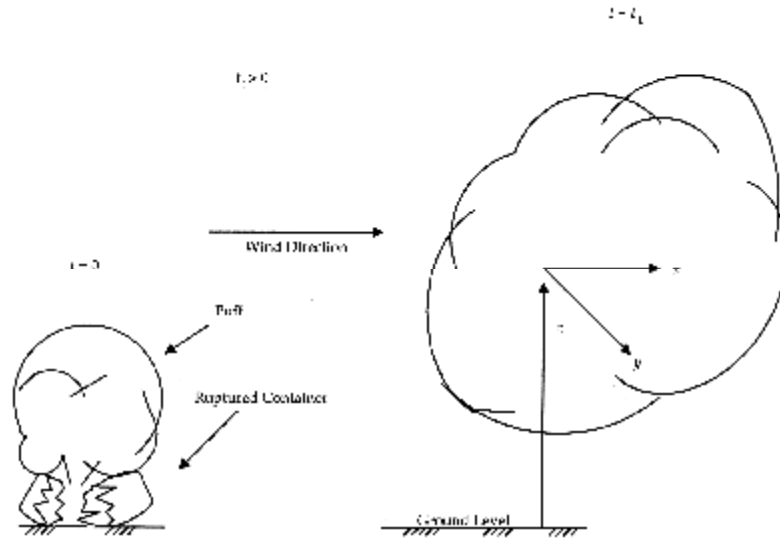

Figure 2.1: Instantaneous source puff model

The resulting puff of vapor and the entrained liquid are dispersed in and carried with the surrounding wind. Downwind concentration (vapor only) is computed using Eq. 2.1

$$C(x,y,z,t) = \frac{Q_m^*}{(2p)^{\frac{3}{2}} s_x s_y s_z} \exp\left[-\frac{1}{2}\left(\frac{y}{s_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H_r}{s_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H_r}{s_z}\right)^2\right]\right\} \quad (2.1)$$

Where Q_m^* is the instantaneous source (mass) and the other variables are as described in the plume model. The computed concentrations are for positions projected from the center of the puff as it drifts downwind at the speed of the surrounding wind.

The dispersion coefficients used with the Pasquill – Gifford puff model are given in Fig. 2.2 and 2.3. Since the puff moves at the same speed as the surrounding wind, the center of the puff is followed using Eq. 2.2.

$$x = ut \quad\quad\quad (Eq. 2.2)$$

Where:

x is the center of the puff and downwind from the source (length),

u is wind speed (length/ time), and

t is time after the source is released (time).

Just as the plume model set $z = 0$ to estimate downwind ground – level concentration using Eq. 1.1, so too does the puff model use Eq. 2.1to estimate ground - level concentration by setting $z = 0$. The center concentration for a ground level release is estimated by setting $y = z = H_r = 0$:

$$C(x,0,0,t) = C(ut,0,0,t) = \frac{Q_m^*}{(2p)^{\frac{3}{2}} s_x s_y s_z} \quad\quad (Eq. 2.3)$$

The stability classes for the puff model are given in Table 1.1. For the specific concentration, the isopleths at the ground level are determined using Eq. 2.4:

$$y = s_y \sqrt{2\ln\left(\frac{C(x,0,0,t)}{C(x,y,0,t)}\right)} \quad\quad (Eq. 2.4)$$
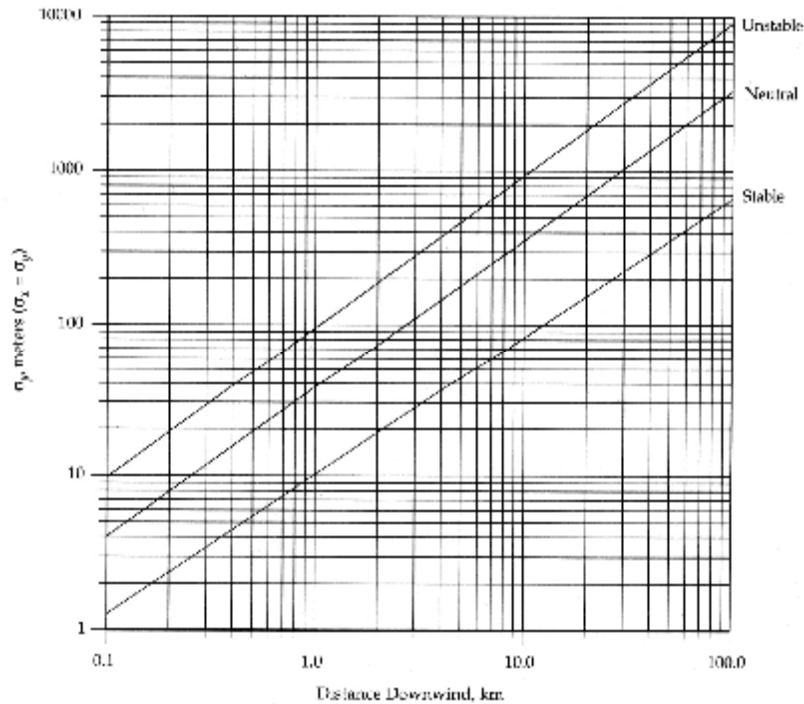
Figure 3.2: Horizontal dispersion coefficients for Pasquill – Gifford puff model
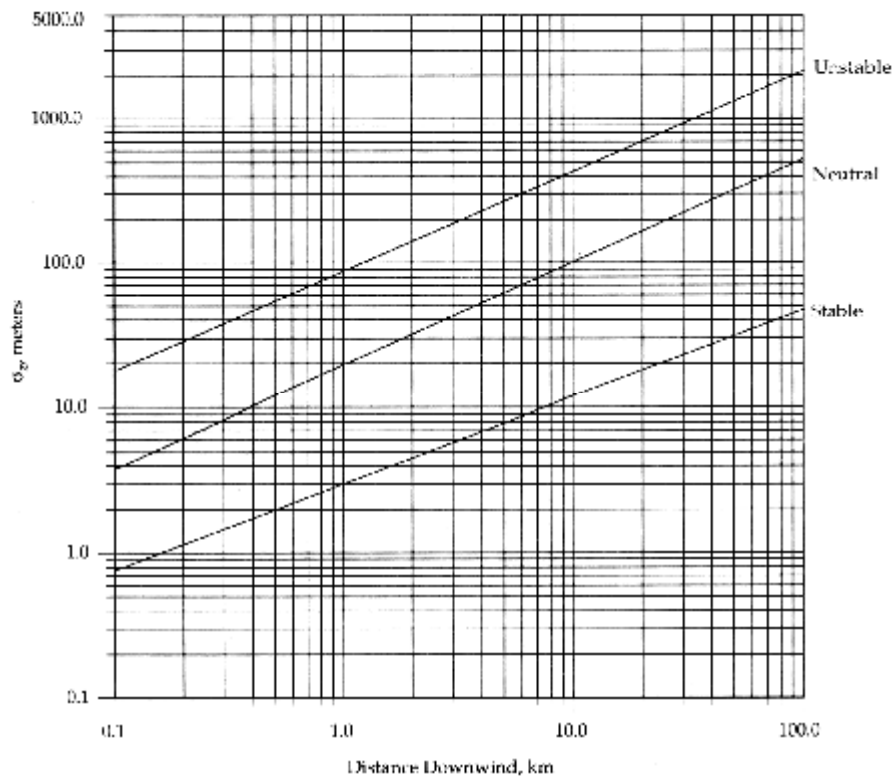

Figure 3.3: Vertical dispersion coefficients for Pasquill-Gifford puff model

III.   APPLYING

We can apply those mathematical models in order to calculate the dispersion of the hazard gas in the air to predict the impact of the environmental risk in using the LPG in Vietnam.

6

DATA:

Determine the maximum downwind concentration at a distance of 10 km from a ground – level source if the source is continuous (1 kg/ sec), the wind speed is 5 m/sec, and it is an overcast night.

SOLUTION:

The maximum concentration of a plume is long the centerline. Since this is a ground – level source, the concentration is determined using Eq. 1.10:

$$C(x,0,0) = \frac{Q_m}{p s_y s_z u}$$

The weather condition are described in Table 1.1; that is, the stability is D, which corresponds to the 5 m/sec wind velocity and an overcast night. The dispersion coefficients are taken from Figs. 1.1 and 1.2:

$$s_x = s_y = 500m \text{ and } s_z = 130m$$

Therefore:

$$C(10,0,0) = \frac{1(kg/\sec)}{3.14 x 500(m) x 130(m) x 5(m/\sec)} = 9.79 x 10^{-3} (kg/m^3)$$

Molecular weight of the LPG (for example: n-butane (C_4H_{10}) is 58.08, the concentration can be computed in ppm:

$$C_{ppm} = R_g \frac{T}{PM}(mg/m^3)$$

$$C_{ppm} = \left(0.08205 \frac{latm}{g-moleK}\right)\left(\frac{298K}{(1atm) x (58.08g/g-mole}\right)(0.979mg/m^3) = 0.412 ppm$$

IV.   CONCLUSION

Result of our study can use for assessing the environmental risk or predicting the consequence of the environmental risk in using LPG or the refrigerant or another hazardous chemicals.

REFERENCE

1.   ***Joseph F. and B. Diane Louvar;*** Health and environmental risk analysis*; Prentice Hall, Inc., 1998.

2.   ***Daniel A. Crowl/ Joseph F. Louvar;*** Chemical Process Safety: Fundamentals with Applications; Prentice Hall, Inc., 2001.